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FULL-SCALE FLIGHT TEST OF A PROPOSED ABORT-ESCAPE SYSTEM
FOR A MANNED SPACE CAPSULE FROM SEA LEVEL

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TECHNICAL MEMORANDUM X-351

FULL-SCALE FLIGHT TEST OF A PROPOSED ABORT-ESCAPE SYSTEM

FOR A MANNED SPACE CAPSULE FROM SEA LEVEL*

By Willard S. Blanchard, Jr., and Sherwood Hoffman

SUMMARY

A proposed system designed to provide safe escape for a manned capsule during the atmospheric part of the boosted flight has been investigated to determine its ability to function properly in case of booster-rocket malfunction at or near take-off. The capsule consisted of a truncated cone with a spherical segment on the large end and a cylinder on the small end. An escape tower, or pylon, with an XM19 (Recruit) rocket motor was mounted on the small end of the capsule with a 1-inch thrust offset. The capsule also contained a drogue parachute and a main parachute for landing.

The escape motor provided sufficient altitude for successful ejection of the drogue and main parachutes. The main parachute functioned satisfactorily and provided a stabilized sinking rate of about 32 feet per second at sea level. Accelerations about the three axes were within the tolerances of a properly positioned and supported human throughout the flight.

INTRODUCTION

The National Aeronautics and Space Administration is devoting considerable effort to the design of capsules for safe manned flight into space, reentry, and landing. One promising vehicle, which has been given much attention for manned flight, consists of a conical-shaped capsule that is located on the forward end of a large booster rocket motor. The capsule is boosted into orbit with its small end forward and reenters with its large end forward. It is important from a safety aspect that such a vehicle be equipped with an escape system to protect an occupant should a failure or malfunction occur during the boosting phase of flight. Since the capsule is designed to be aerodynamically stable with its large end forward (reentry configuration), a stability problem exists when the capsule is aborted from the booster with its small end forward. A safe abort system, therefore, would require that the capsule, in the escape configuration, be stable small end forward in order to avoid the high transverse loads that would be associated

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with an immediate turnaround during an escape maneuver at high dynamic pressure. In addition, the capsule should have a system which is capable of providing (1) sufficient altitude for a parachute recovery system to function properly in case of sea-level abort just prior to launch, (2) adequate acceleration away from a malfunctioning booster during atmospheric flight, and (3) a reliable landing system.

Small-scale-model tests conducted by the Applied Materials and Physics Division at the Langley Research Center, in the Langley 20-foot free-spinning tunnel, showed that one promising method of stabilizing the capsule for the escape from the booster consisted of mounting a rocket motor on a tower (or vertical pylon) from the small end of the capsule. In support of Project Mercury, additional tests of the system were undertaken to prove its practicability for full-scale models of the capsule. This paper reports on a flight test of the system simulating escape from the forward face of a booster prior to take-off. A full-scale model was flown off the beach at the NASA Wallops Station in April 1959 to determine the capsule motions and accelerations (1) during escape-motor thrusting with a deliberate 1-inch thrust offset, (2) after tower release, and (3) with a large landing parachute.

The model was tracked with radar and with motion-picture cameras and longitudinal, normal, and transverse accelerations were telemetered to ground receiving stations during the flight.

SYMBOLS

A_L	longitudinal accelerometer reading, positive toward pylon, g units
A_N	normal accelerometer reading, g units
A_T	transverse accelerometer reading, g units
F	thrust, lb
g	acceleration due to gravity, 32.2 ft/sec ²
h	altitude, ft
I_Y	moment of inertia in pitch, slug-ft ²
I_Z	moment of inertia in yaw, slug-ft ²
M_Y	moment in pitch, ft-lb

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M_Z	moment in yaw, ft-lb
N_{Re}	Reynolds number, based on maximum diameter of capsule
p	free-stream static pressure, lb/sq in.
R	range, ft
R_x	range component along abscissa, ft
R_y	range component along ordinate, ft
T	free-stream temperature, $^{\circ}F$
t	time, sec
V	velocity along flight path, ft/sec
x	distance along longitudinal axis, measured from maximum diameter, positive toward pylon, in.
x_{cg}	center-of-gravity location along longitudinal axis, measured from maximum diameter, positive toward pylon, in.
ρ	free-stream density, slugs/cu ft
$\ddot{\theta}$	angular acceleration in pitch, radians/sec ²
$\ddot{\psi}$	angular acceleration in yaw, radians/sec ²

MODEL

The general arrangement and the dimensions of the full-scale model are presented in figure 1. The take-off or escape configuration, as shown in figure 1(a), consisted of the capsule, a vertical tower or pylon rising from the small end of the capsule, and an escape rocket motor mounted on top of the pylon. At take-off, the vehicle had a center of gravity 77 inches from the heat-shield juncture, a weight of 2,580 pounds, and a moment of inertia in pitch of 5,100 slug-ft². At burnout (without the rocket grain) the center of gravity was 55 inches from the heat-shield juncture, the weight was 2,118 pounds, and the moment of inertia in pitch was about 3,000 slug-ft².

The capsule (fig. 1(b)) had an 80-inch maximum diameter, a spherical segment for its heat-shield or reentry nose, a 23^o half-angle truncated cone for a midsection, and a cylindrical parachute compartment. The conical and cylindrical parts were constructed of 1/8-inch steel plates,

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the heat shield of 3/16-inch steel, and the parachute compartment of aluminum. The capsule was ballasted to locate the center of gravity 15.50 inches rearward of the heat-shield juncture and had a total weight (without the chutes) of 1,730 pounds. The moments of inertia were approximately 400 slug-ft² in pitch and yaw, and about 260 slug-ft² in roll.

The parachute compartment contained two chutes. The first was a 42-inch-diameter, three-point-suspension, nylon drogue parachute with porosity of 23 percent and riser length of 30 feet. The second or main parachute was a 46-foot-diameter, extended-skirt, nylon chute with porosity of about 15 percent, shroud length of 60 feet, and riser length of 6 feet. The parachute deployment bag had a free-sliding fit in the cannister and was tied down with light (50-pound) lines. The main parachute was reefed and the reefing cutter contained a 2-second-delay squib. The compartment also contained a lid gun for blasting off the cannister top, an aluminum mortar for ejecting the drogue parachute, and a mechanism to release the main parachute from the capsule on water impact.

The pylon shown in figures 1(c) and 1(d) consisted of three longitudinal steel tubes reenforced by steel-tube cross members. Explosive bolts were mounted in each vertical member of the pylon at the points of attachment of the tower to the capsule. The upper end of the pylon was attached to the nozzle block. Three long nozzles were mounted in the nozzle block and equally spaced at intervals of 120°. The nozzles were canted 15° with respect to the vertical center line in order to direct the rocket exhaust away from the capsule. Figure 1(e) shows a section view of one of the nozzles. The escape motor, an XM19 (Recruit) rocket, was ballasted (fig. 1(a)) to stabilize the capsule in the escape configuration.

TEST AND INSTRUMENTATION

A photograph of the full-scale model and the dolly-type launcher used at the NASA Wallops Station is shown in figure 2. The tower assembly was offset 1 inch from the capsule center line in the pitch plane in order to obtain a normal translation during the thrusting part of the flight. A small normal or lateral translation would be required in an actual escape maneuver to divert the capsule from the flight path of a malfunctioning booster.

Two mechanical timers were installed in the model to program the following events: (1) ignition of the explosive bolts in the tower to separate the tower at about 8 seconds after launch, (2) firing of a lid gun to eject the cover of the parachute compartment at about 11 seconds, and (3) firing of a mortar to eject the drogue parachute at approximately

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12 seconds. The drogue parachute was attached to the main parachute deployment bag to pull out the latter from the parachute compartment.

Flight-path data were obtained by tracking the model with the FPS-16 tracking radar, the NASA modified SCR-584 tracking radar, and the Reeves modified SCR-584 radar. Velocity along the trajectory during boosted flight was measured by the CW Doppler velocimeter. The velocity of the capsule with the main parachute open was too low for accurate measurement with the Doppler radar. The low-speed velocities, therefore, were obtained by differentiating the time-history variations of altitude and elevation angle from the modified SCR-584 tracking radar and resolving the components along the flight path. Atmospheric conditions were obtained from a rawinsonde balloon that was launched just prior to the test. Motion pictures of the flight were taken by cameras located near the launching site.

The model was equipped with an NASA six-channel telemeter to measure longitudinal, normal, and transverse accelerations at two stations along the center line. Three accelerometers were mounted about the center of gravity of the capsule (station 15.50 inches in fig. 1(b)) and three were located near the burnout center of gravity of the escape configuration (station 50.0 inches). Continuous accelerometer data were transmitted from the capsule to two ground receiving stations throughout the test.

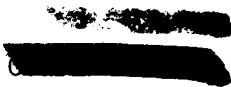
Two 16-mm motion-picture cameras also were installed in the capsule. One was located in the center of the heat shield for an onboard recording of the capsule motions with respect to ground. The second camera was located between the parachute compartment and outer skin to view the burning rocket motor and parachutes.

A preflight ground static test was conducted to determine the thrust characteristics of a typical XM19 (Recruit) rocket motor with the three long nozzles and to determine the structural integrity of the nozzles. The thrust-time history obtained from this ground test is presented in figure 3. Tail-off (time interval during which thrust is rapidly decreasing) occurred at about 1.62 seconds, as shown in figure 3.

Two HUS helicopters operated by the U.S. Marines were employed to recover the capsule and U.S. Navy skin divers were utilized to recover the tower from the water.

RESULTS AND DISCUSSION

Sequence photographs, showing the main events of the flight test, are presented in figure 4. The model was launched at 75° elevation



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from the launching pad as shown in the first photograph. Take-off and powered flight is shown in sequence photographs 2, 3, 4, and 5. A small angular rotation in pitch was obtained from the thrust misalignment. It also should be noted that the exhaust from the three canted nozzles of the Recruit rocket cleared both the tower and capsule. After burnout, photograph 6, the capsule and tower tumbled approximately $1\frac{1}{2}$ revolutions before the tower was released. Photograph 7 shows the separated tower, the ejected lid of the parachute compartment, and the deployed drogue parachute. Sequences 8 to 12 show the main parachute being pulled out of the compartment by the drogue chute, the opening of the main parachute to the reefed condition and the fully opened condition, and the landing of the capsule and parachute in the water. After impact with the water, the main parachute was automatically released from the capsule and the capsule floated like a buoy. Inspection of the steep capsule and tower after recovery showed no heat damage from the nozzle exhaust; the capsule was not damaged upon impact with the water.

The motion pictures obtained from the onboard cameras gave a pilot's view of the capsule during the escape maneuver. The upper camera showed that the rocket exhaust flowed smoothly from the three nozzles and that all the separation events occurred without any noticeable interference. The lower camera showed that the angular rotation started shortly after take-off and that at the time of impact with the water there was virtually no oscillation of the capsule.

The variations of free-stream density, pressure, and temperature with altitude for the test are given in figure 5. The flight Reynolds numbers (based on maximum diameter) shown in figure 6 varied from 27×10^6 near burnout of the escape motor to about 2.3×10^6 at splash. The time-history variation of center of gravity is presented in figure 7.

An isometric view of the flight trajectory, the variations of altitude with range, and a horizontal projection of the trajectory are shown in figures 8 to 10, respectively. The model was launched approximately downwind and experienced about a 20° change in azimuth during burning of the rocket motor, indicating thrust asymmetry in the lateral plane. The escape motor burned out at an altitude of about 550 feet and tower separation occurred near 2,000 feet. The parachute compartment lid and the drogue chute were ejected near the apex of the trajectory at 2,080 feet. The main chute was fully opened near 1,200 feet altitude after which the model drifted in the general direction of the wind. It should be noted that the wind azimuth shown in figures 8 and 10 is for surface winds at the launching site. These surface winds were about 30 feet per second during the test. Splash occurred at a range of 2,300 feet approximately 56.7 seconds after launch.

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Figure 11 shows the variation of velocity with time along the flight path. The maximum velocity occurred 1.6 seconds after take-off and was 615 feet per second. The tower was released at a flight-path velocity of 130 feet per second, the lid at 55 feet per second, and the drogue parachute at 55 feet per second. The main parachute stabilized the capsule at a velocity of about 200 feet per second. The vertical velocity component near impact was about 32 feet per second.

The time-history variations of longitudinal, normal, and transverse accelerations as measured by the accelerometers are presented in figure 12. The accelerations at station 15.50 are those which would be experienced by an astronaut during an escape maneuver from the launching pad. The maximum longitudinal acceleration was 13.5g and lasted for about 0.4 second. The maximum acceleration between burnout and splash never exceeded 13g in either the longitudinal, normal, or transverse directions. The data also show that the capsule and tower had pitched one-half of a revolution 4.2 seconds after take-off. At this time A_L had reached a maximum positive value for decelerating flight and A_N and A_T were approximately zero. Time-history plots between 21 seconds and 56 seconds have been omitted from figure 12 since the variations of the accelerometer readings were small (less than ± 1 g). These accelerations were within the tolerances of a properly positioned and supported human throughout the flight.

Impact of the capsule with the water occurred between 56.6 seconds and 56.8 seconds. The accelerometer readings for this interval have been omitted because the frequency response of the accelerometers was not sufficient to measure the impact loads g accurately.

The normal and transverse accelerometer readings at the two longitudinal stations are indicative of the angular accelerations in pitch and yaw. The angular accelerations presented in figure 13 were computed from the following expressions:

$$\ddot{\theta} = 32.2(12) \left(\frac{A_{N50} - A_{N15.5}}{x_{50} - x_{15.5}} \right)$$

and

$$\ddot{\psi} = 32.2(12) \left(\frac{A_{T50} - A_{T15.5}}{x_{50} - x_{15.5}} \right)$$

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where numerical subscripts indicate longitudinal stations of the accelerometers. It should be noted that large percentage errors in $\ddot{\theta}$ and $\ddot{\psi}$ may be obtained when the differences in the accelerometer readings are small, but for these cases, the angular accelerations also are small.

The data indicate that the maximum angular accelerations were less than ± 8 radians/sec² during the thrusting interval of the escape motor with 1-inch thrust offset and less than ± 15 radians/sec² under descending flight with the main parachute opened. The angular velocity rates during the tumbling stage of the vehicle were determined by integrating the area under the curves in figure 12 and found to be about 1.2 radians/sec in yaw and about 0.6 radian/sec in pitch. Motion-picture tracking records indicated an average rotational velocity of about 1.5 radians/sec.


The pitching and yawing moments during the flight are proportional to $\ddot{\theta}$ and $\ddot{\psi}$ values shown in figure 13 and may be determined from $M_Y = I_Y \ddot{\theta}$ and $M_Z = I_Z \ddot{\psi}$. The maximum moment was obtained 0.2 second after launch and was approximately 38,000 foot-pounds in yaw. The largest moment obtained after the main parachute opened was about 5,600 foot-pounds in pitch.

CONCLUSIONS

A proposed escape system for a manned capsule has been investigated by a full-scale flight test from a launching pad at sea level. The capsule was equipped with a Recruit rocket motor mounted on a vertical tower or pylon and a large parachute for landing. The results indicate the following conclusions:

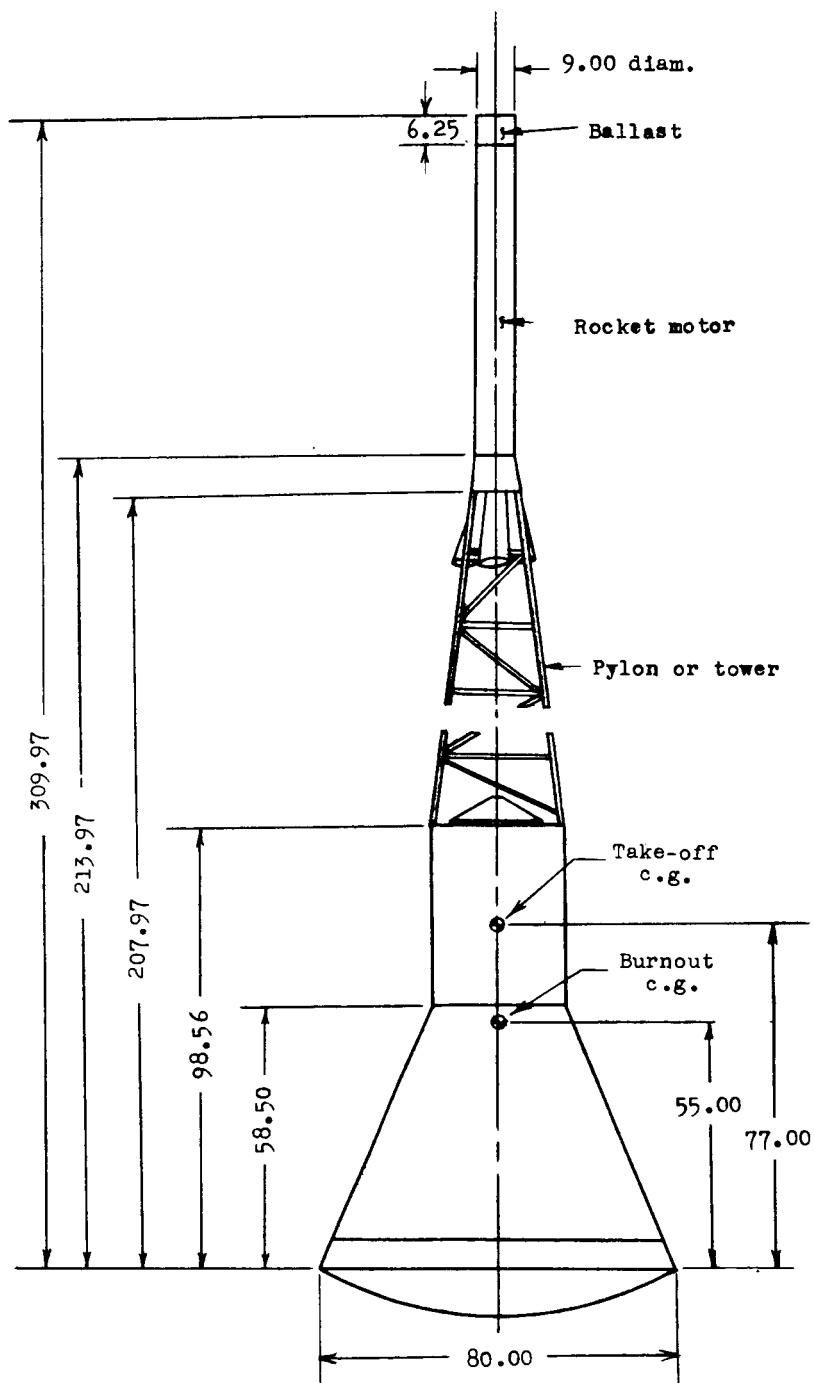
1. Accelerations about the three axes were within the tolerances of a properly positioned and supported human throughout the flight.
2. The escape system performed satisfactorily and provided sufficient altitude for successful ejection of the drogue parachute and subsequently the main, or landing, parachute.
3. The landing parachute functioned satisfactorily and provided a stabilized sinking rate of about 32 feet per second at sea level.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 30, 1960.



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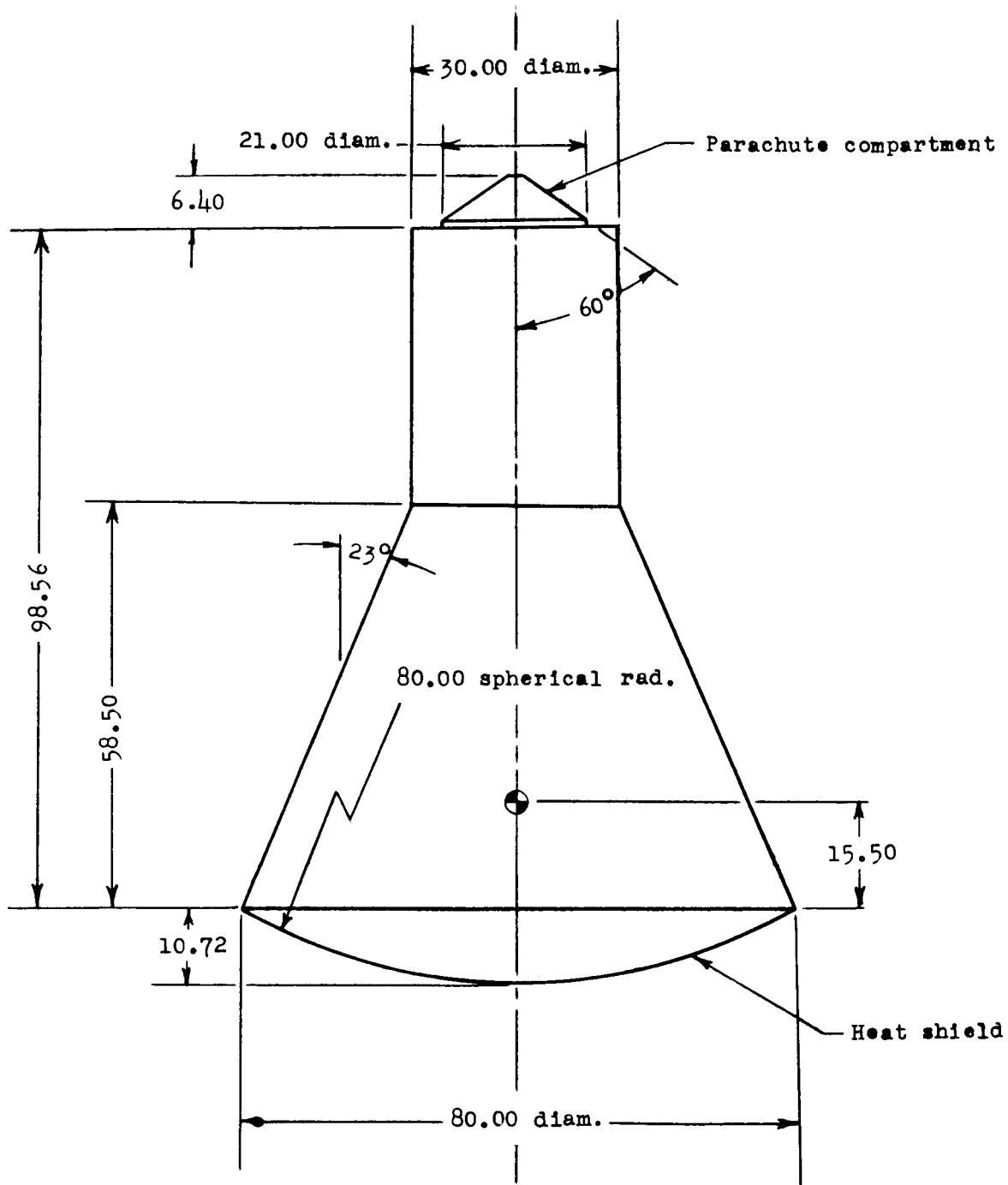
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(a) Capsule, pylon, and escape-rocket-motor assembly.

Figure 1.- Details and dimensions of test model. All dimensions are in inches.

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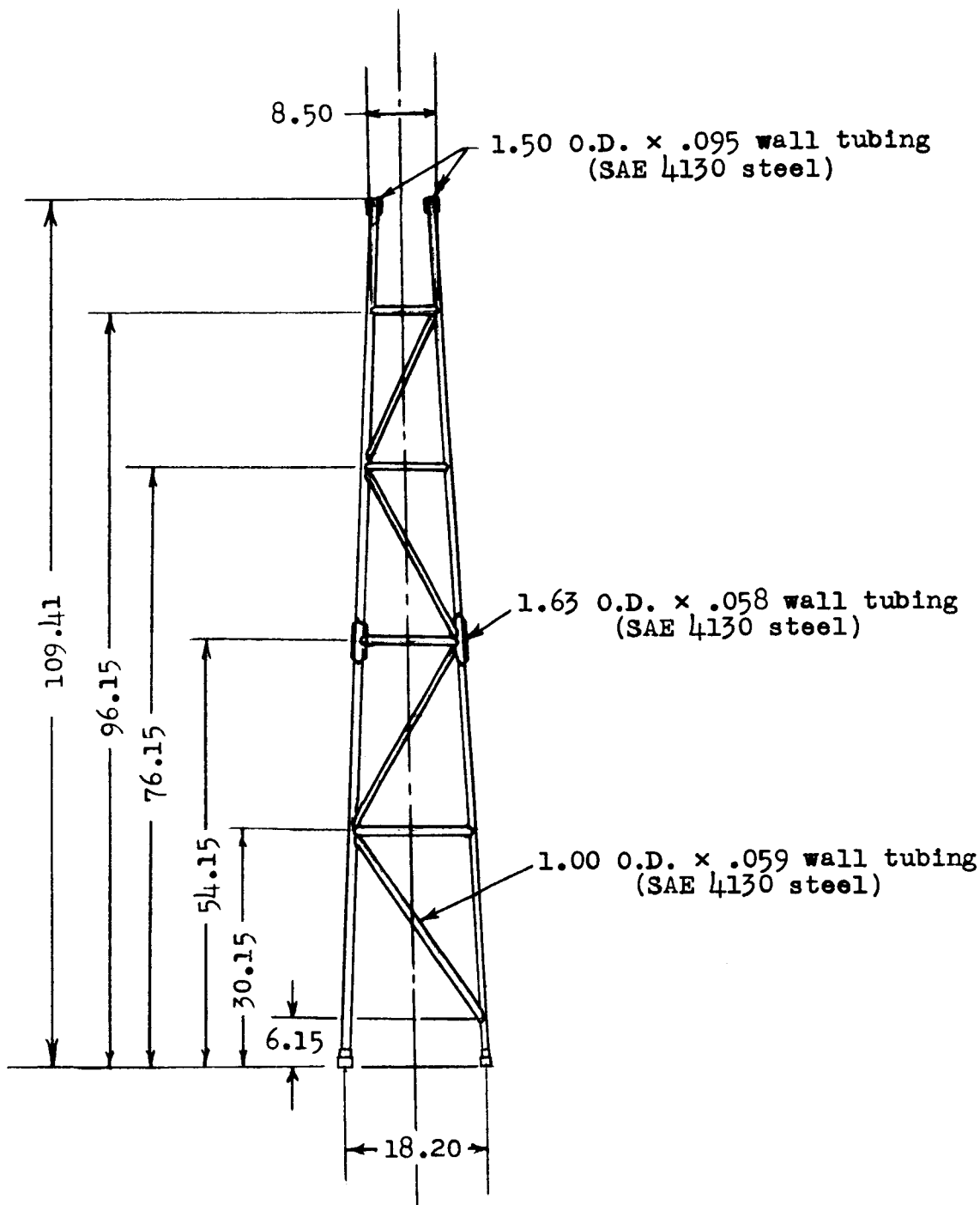


(b) Capsule.

Figure 1.- Continued.

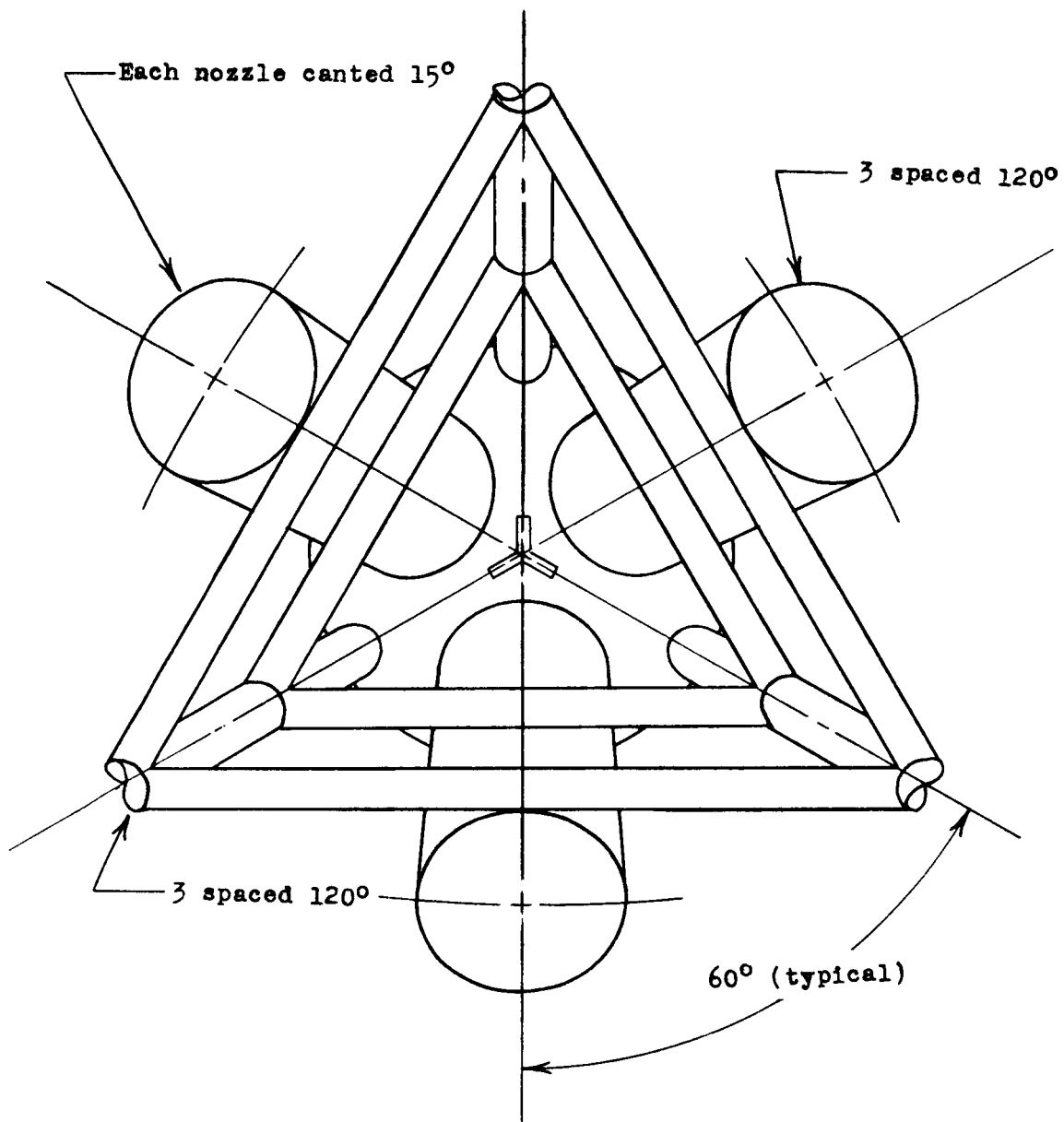
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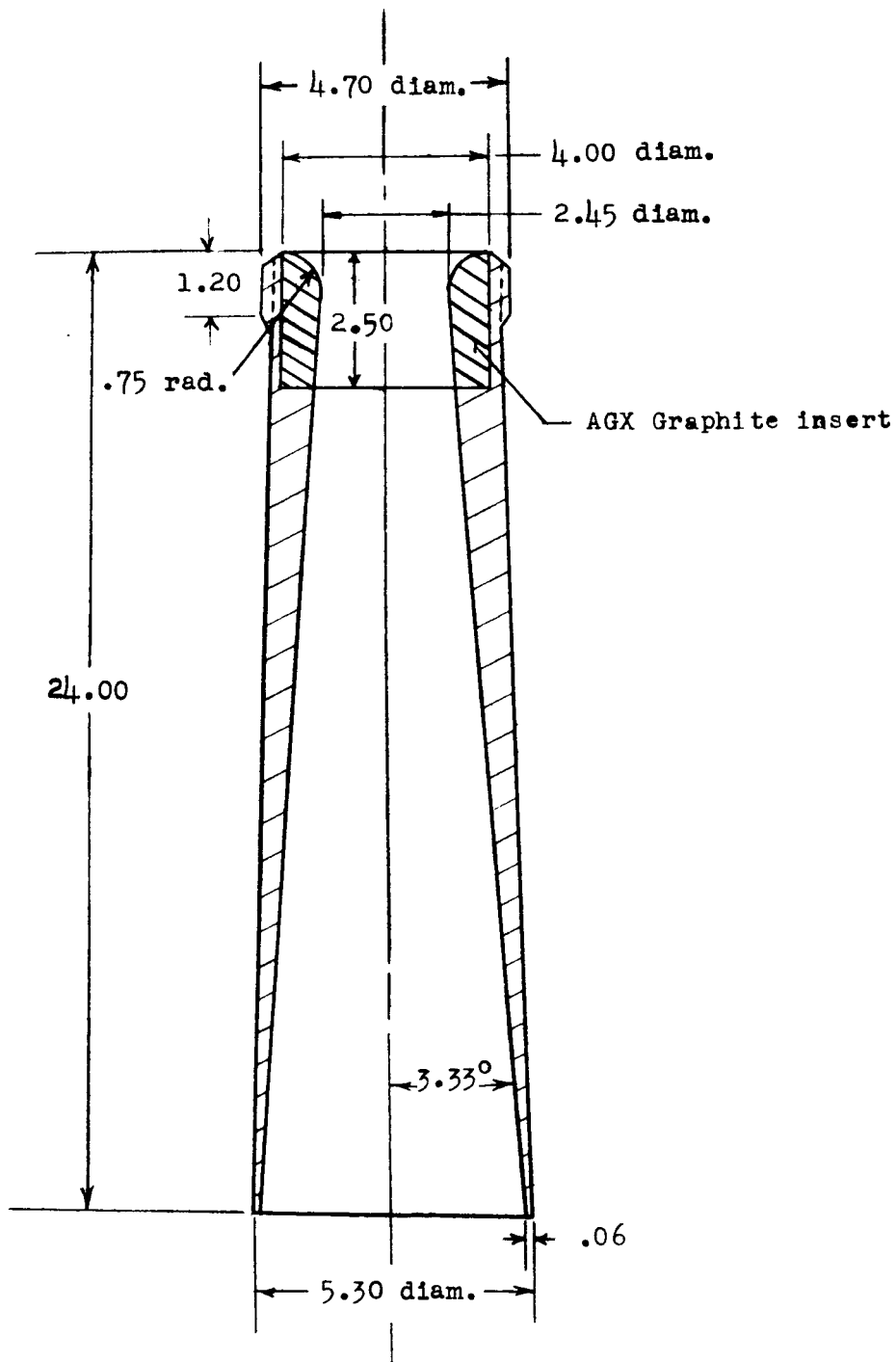
(c) Pylon or tower. This view typical of each of 3 sides of pylon.

Figure 1.- Continued.

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(d) Bottom view of escape motor and nozzles. Trusswork is partially omitted for clarity.

Figure 1.- Continued.



(e) Section view of escape-motor nozzle.

Figure 1.- Concluded.

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Figure 2.- Photograph of capsule and launcher.

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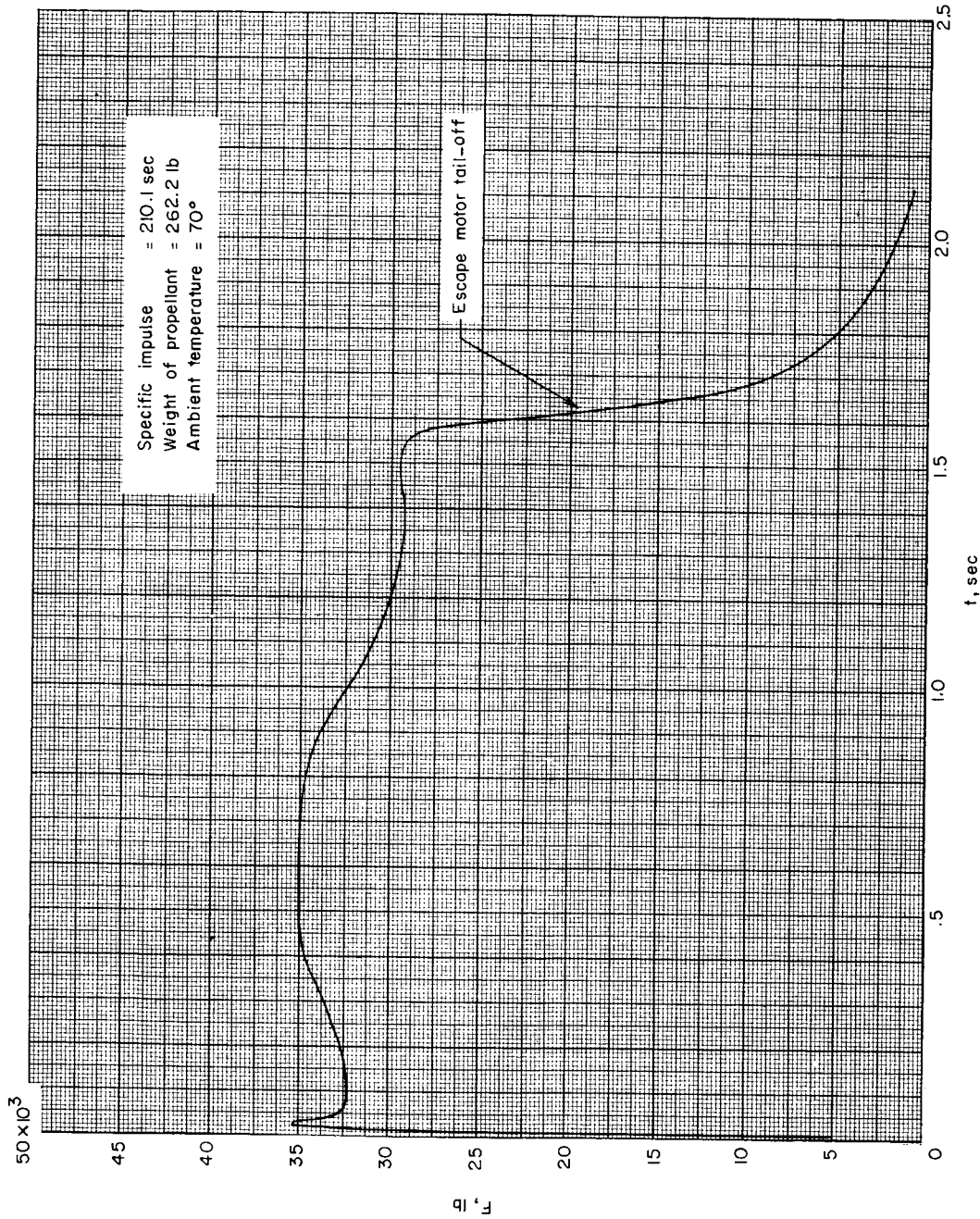
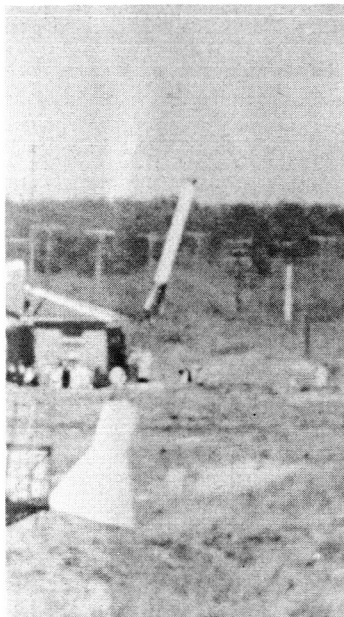
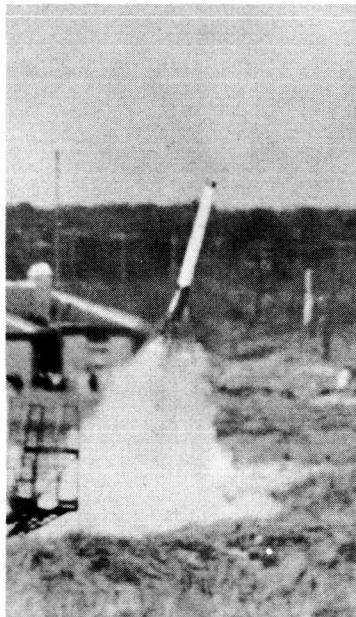


Figure 3.- Measured thrust-time curve for XM19 (Recruit) rocket motor with the three long nozzles at sea level.

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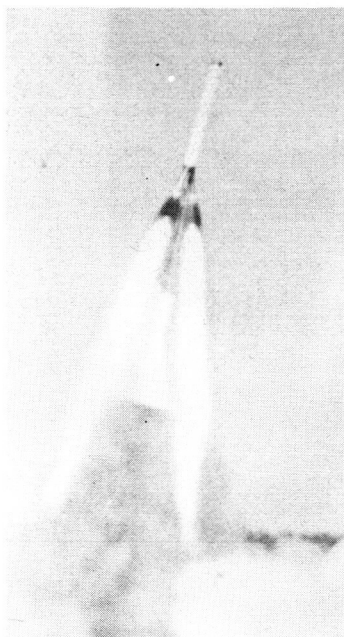
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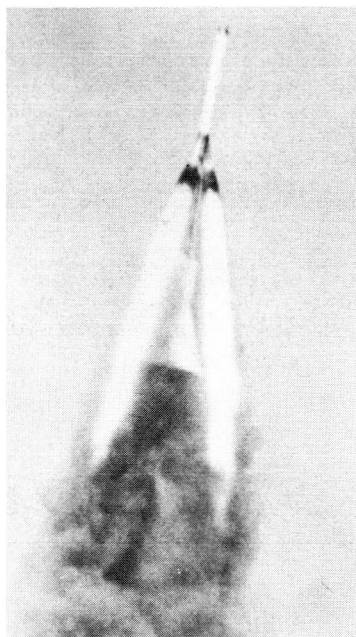
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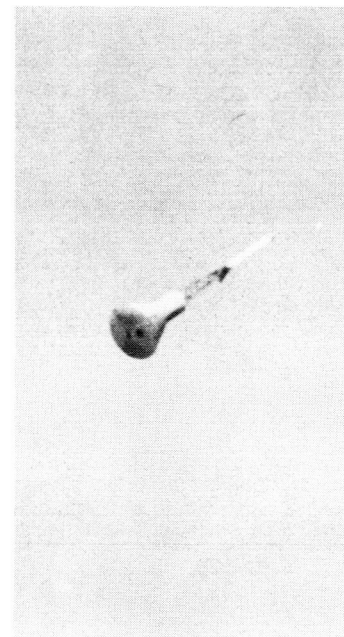
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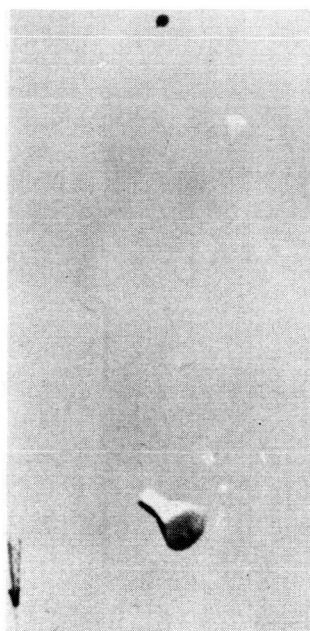


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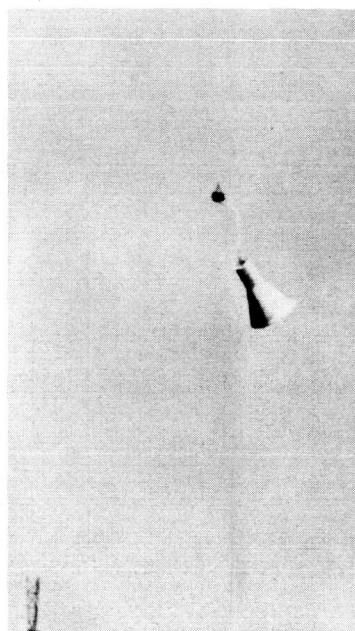
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Figure 4.- Sequence photographs of model during test.

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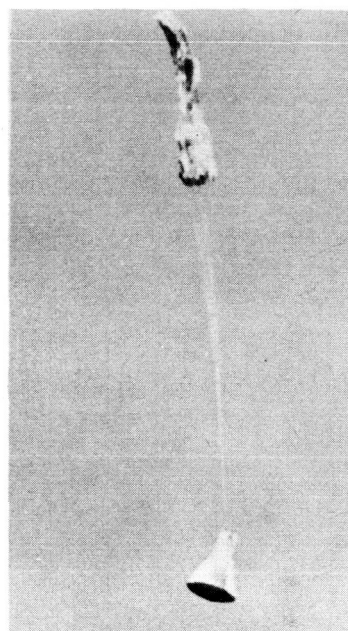
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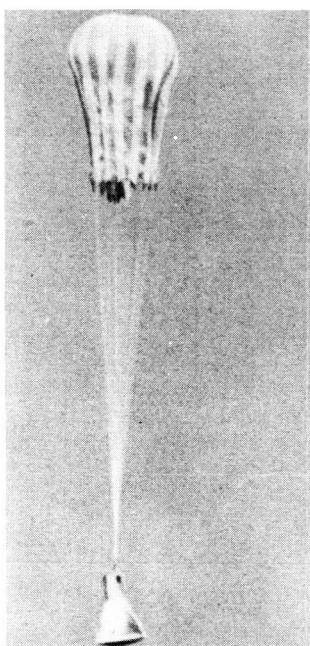
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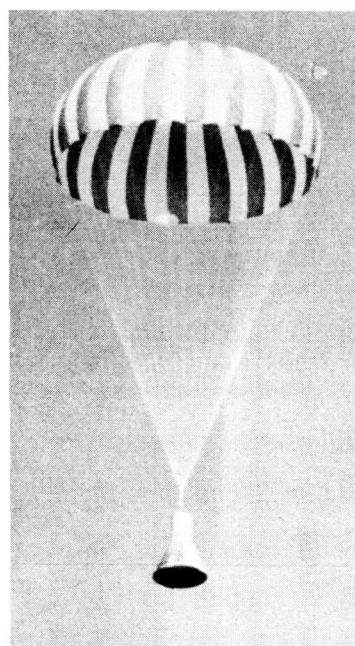
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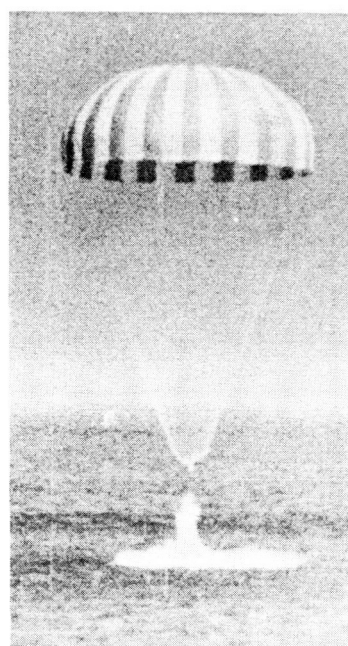
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Figure 4.- Concluded.

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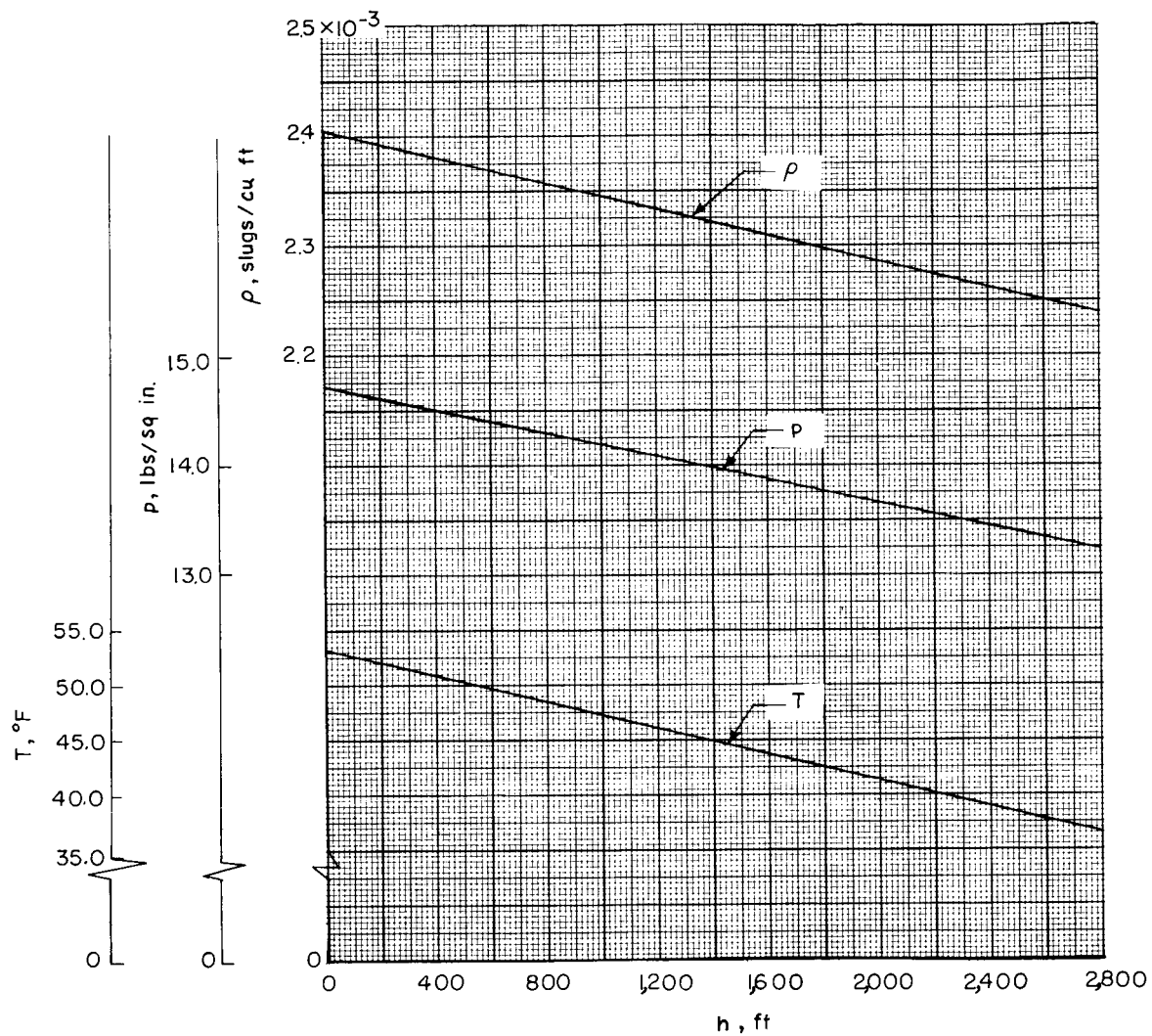


Figure 5.- Free-stream conditions for flight test.

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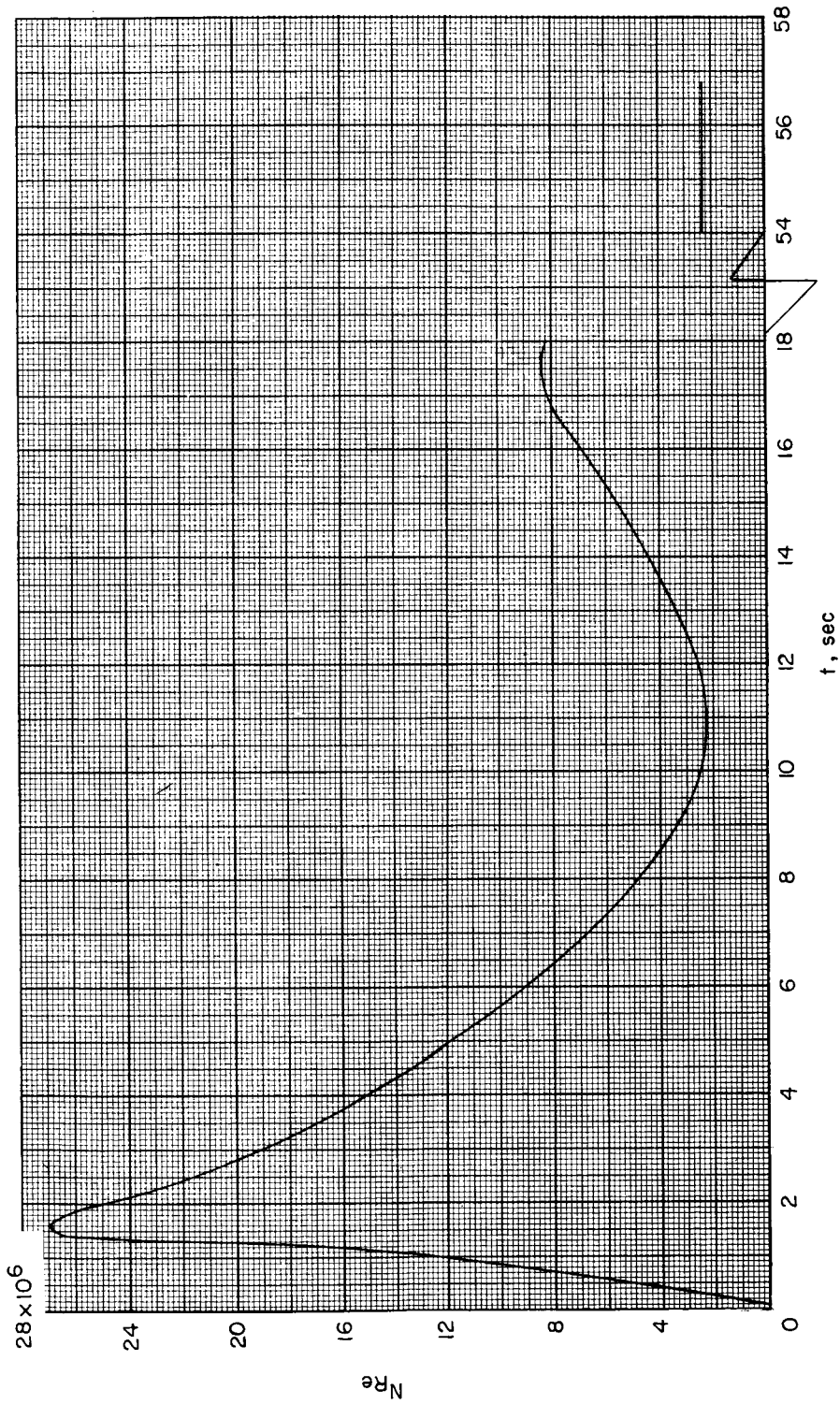


Figure 6.-- Variation of Reynolds number with time.

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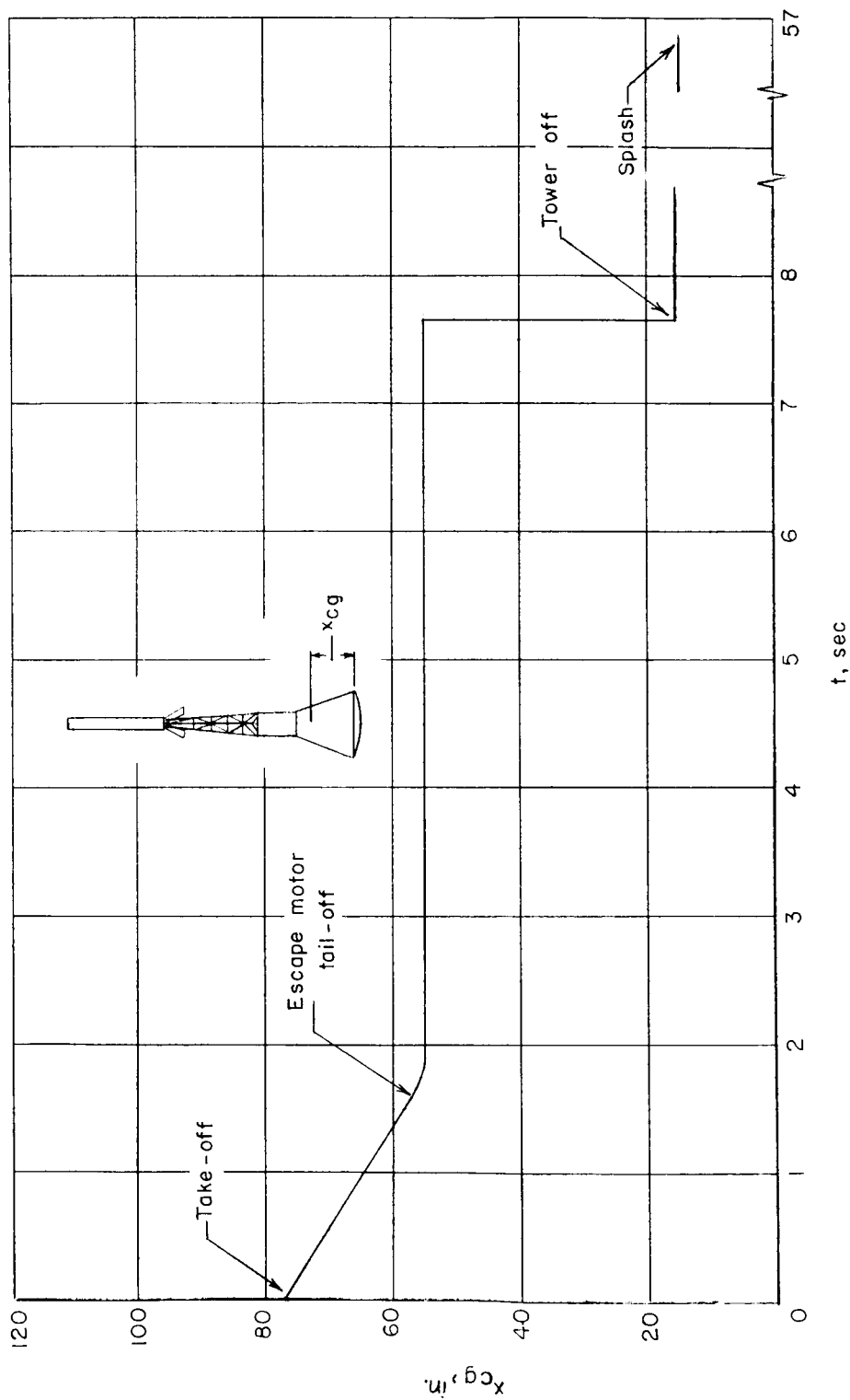


Figure 7.- Variation of center of gravity with time.

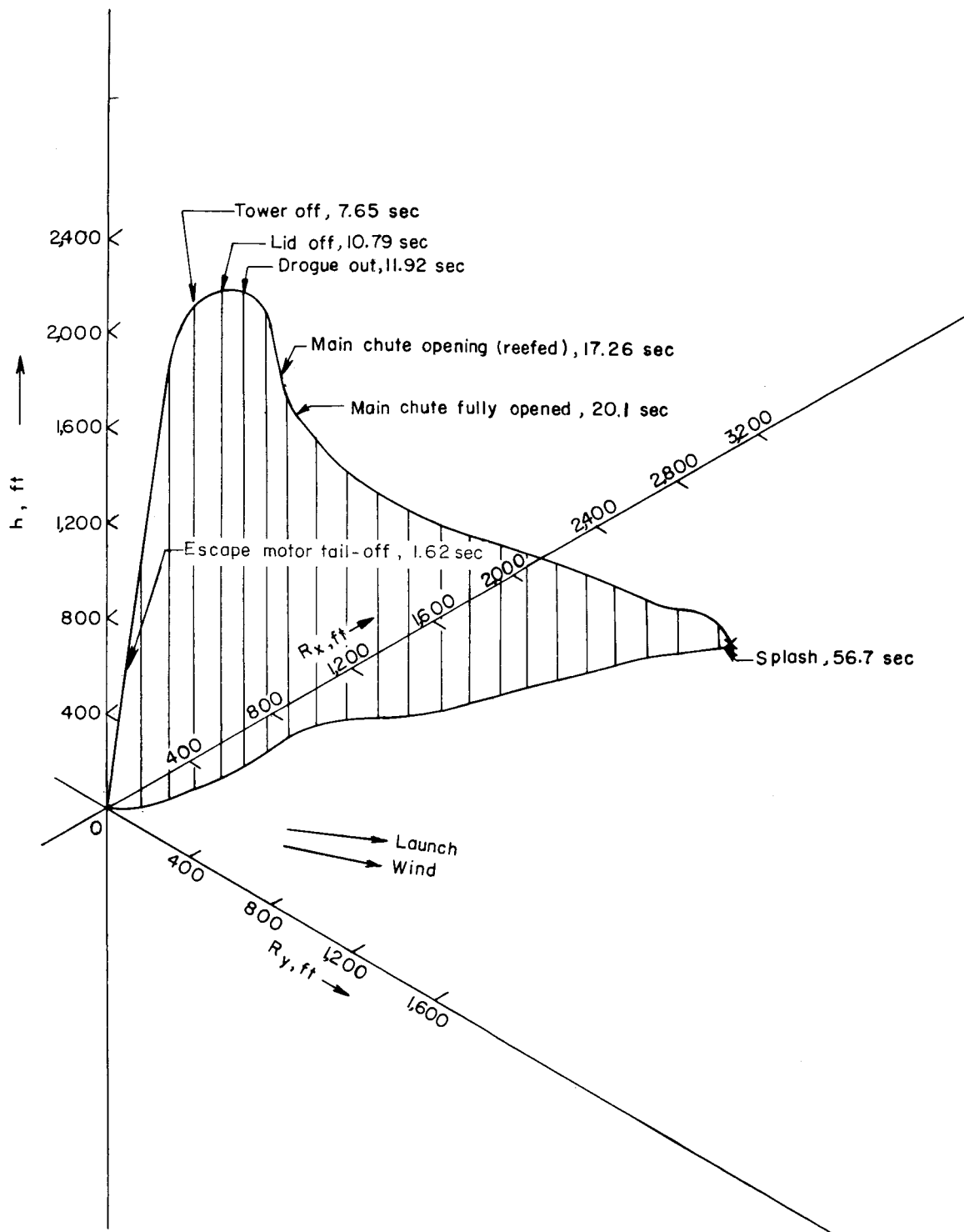
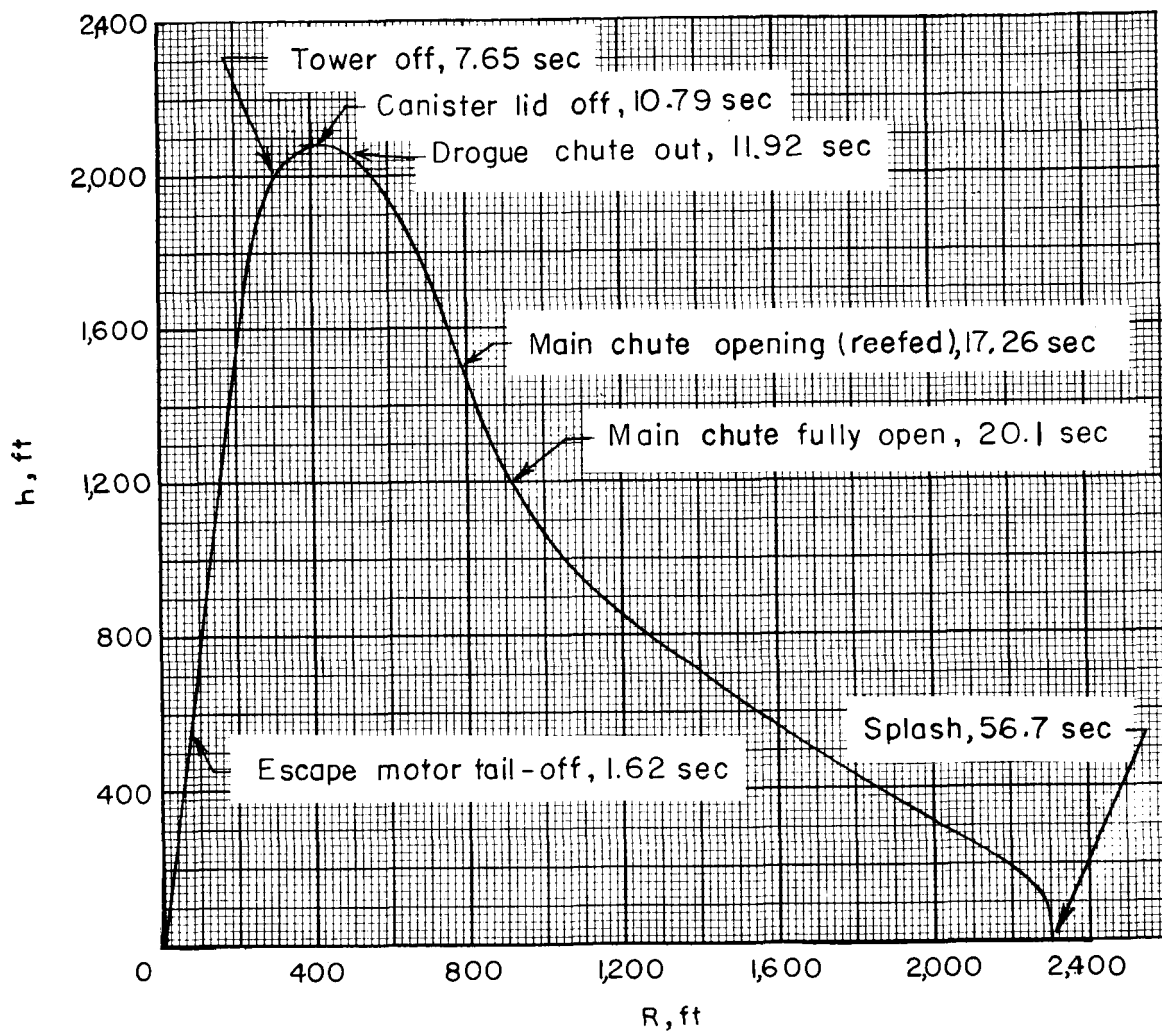


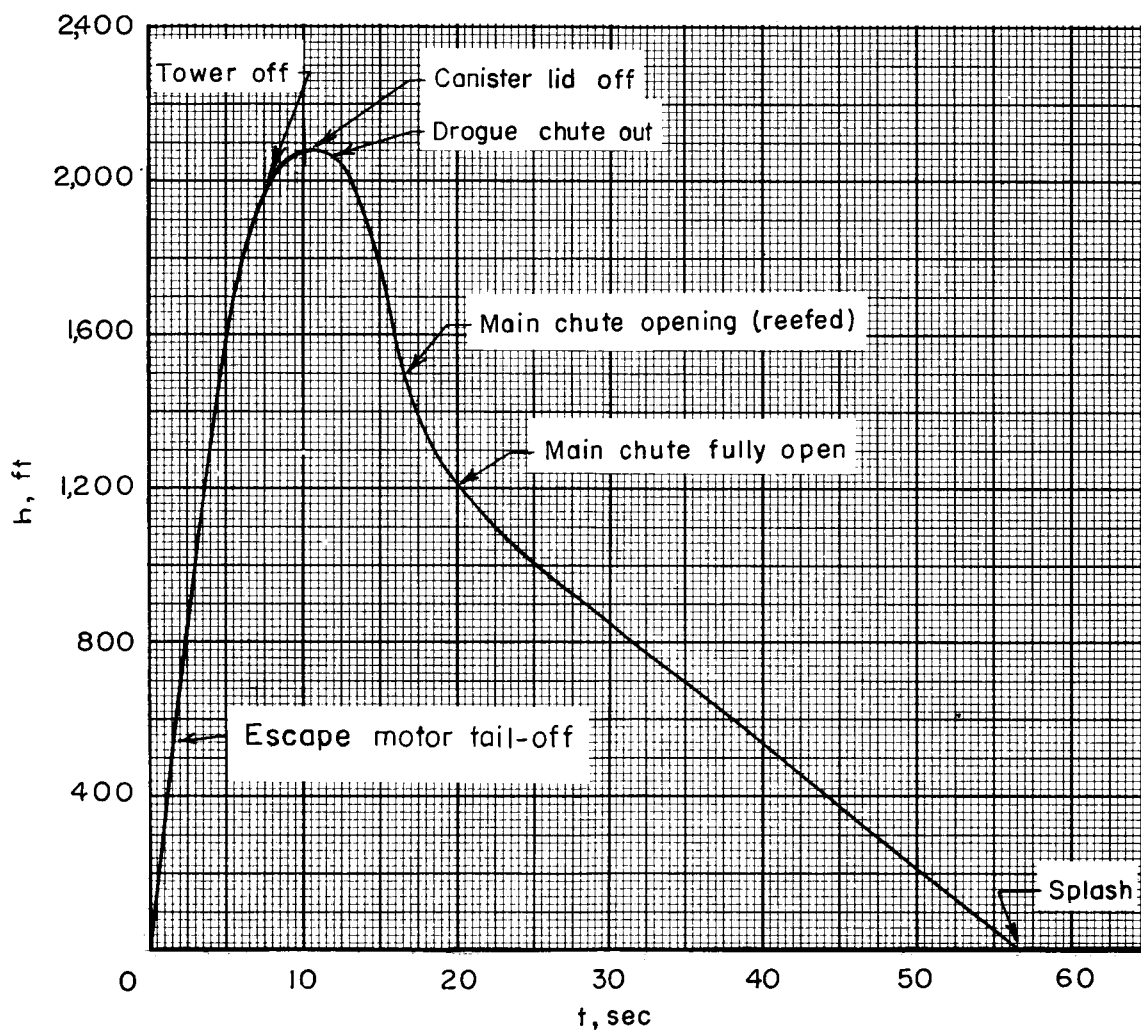
Figure 8.- Model trajectory for the test.

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(a) Altitude and range.

Figure 9.- Variation of altitude with range and time.



(b) Altitude and time.

Figure 9.- Concluded.

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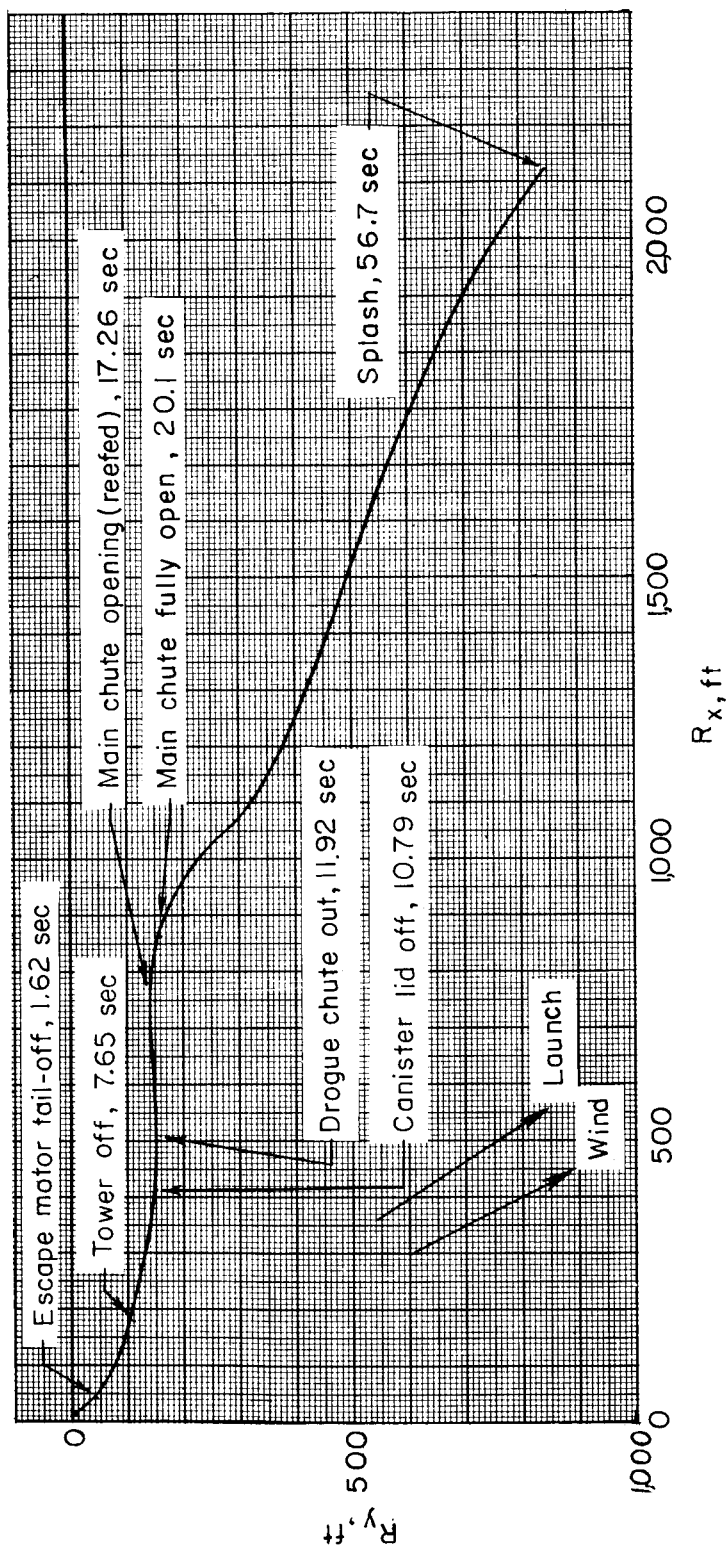


Figure 10.- Projection of trajectory showing the variation of azimuth during the test.

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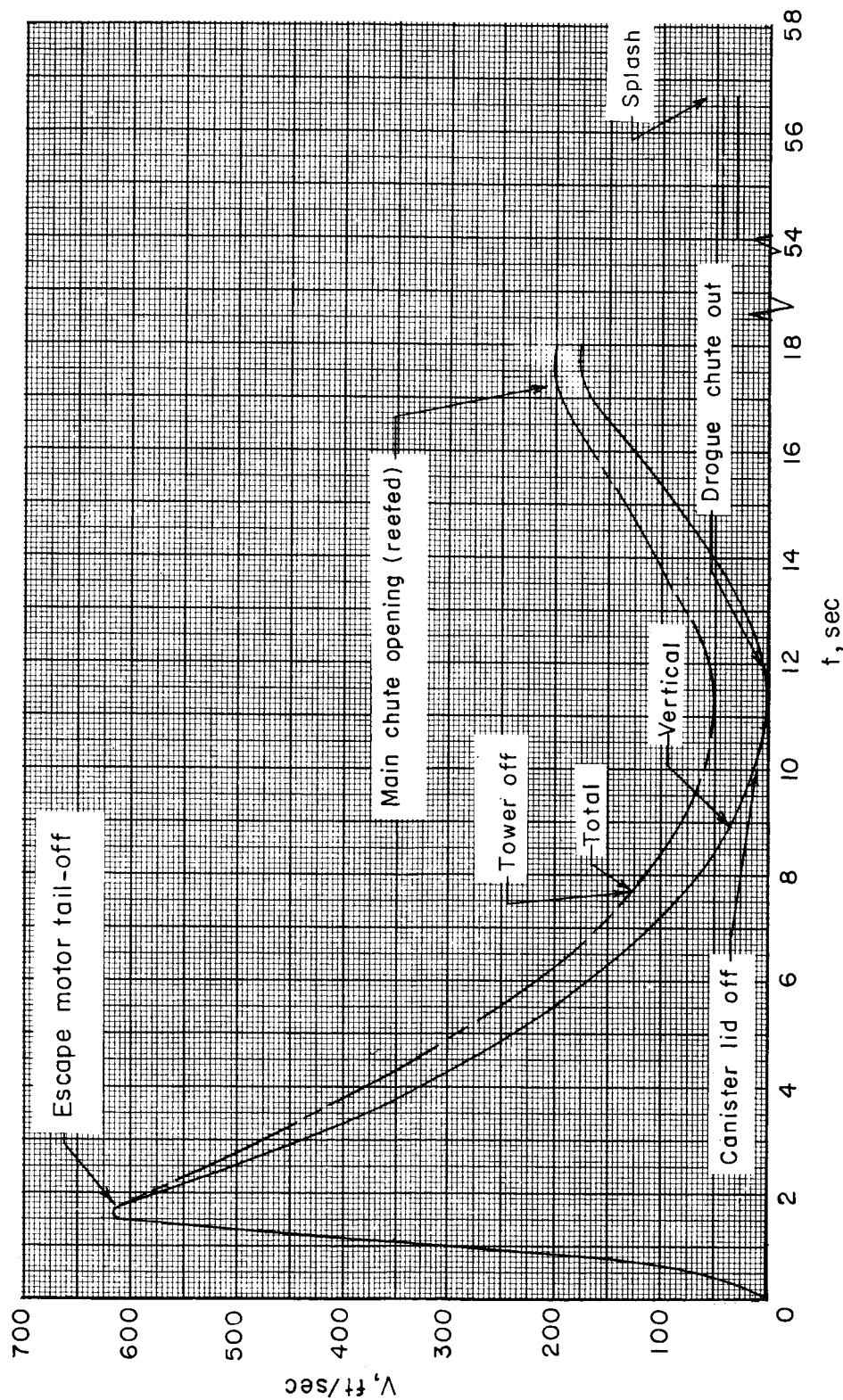
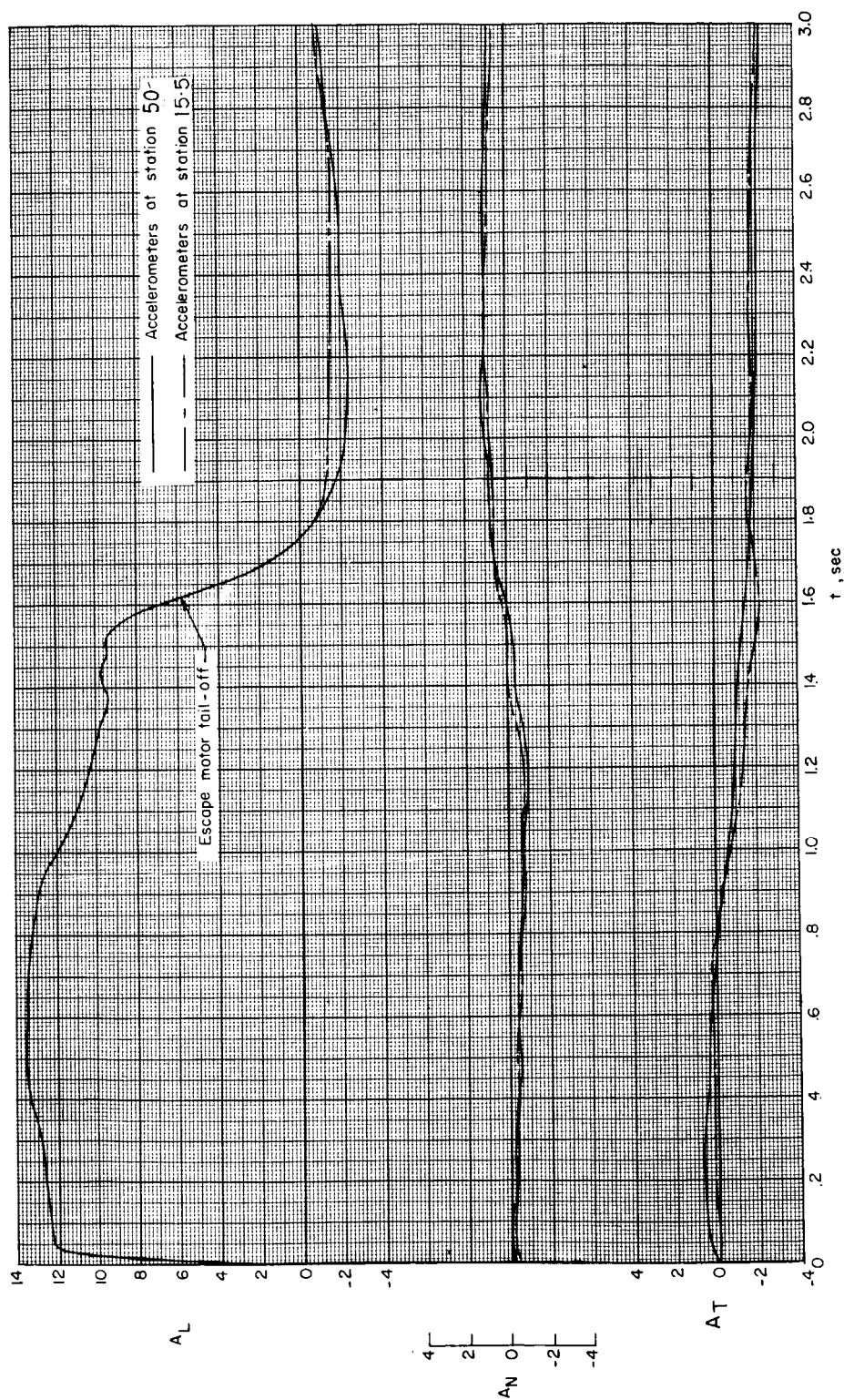


Figure 11.- Variation of velocity along flight path with time.

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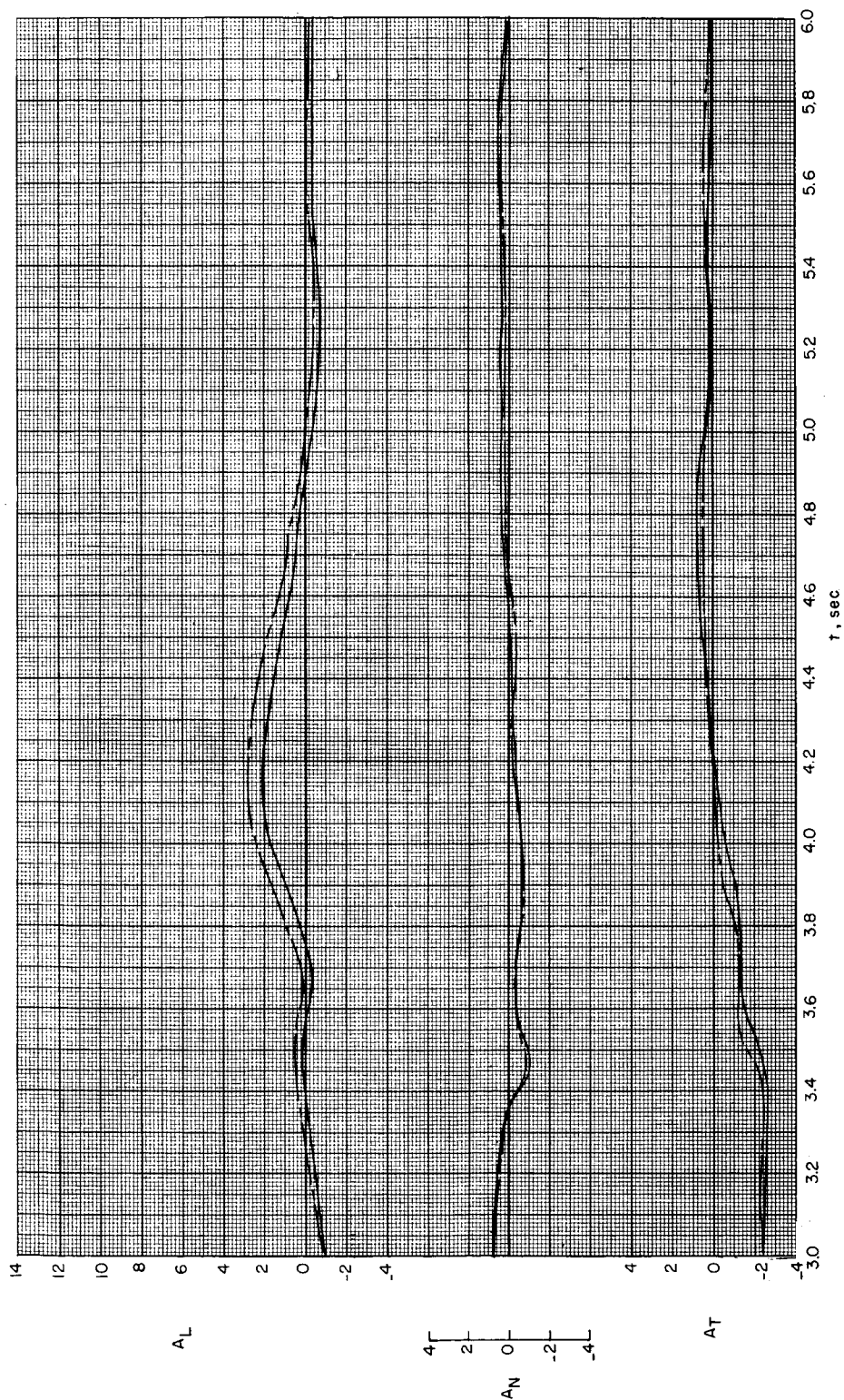


(a) 0 to 3.0 seconds.

Figure 12.- Variations of longitudinal, normal, and transverse accelerations with time.

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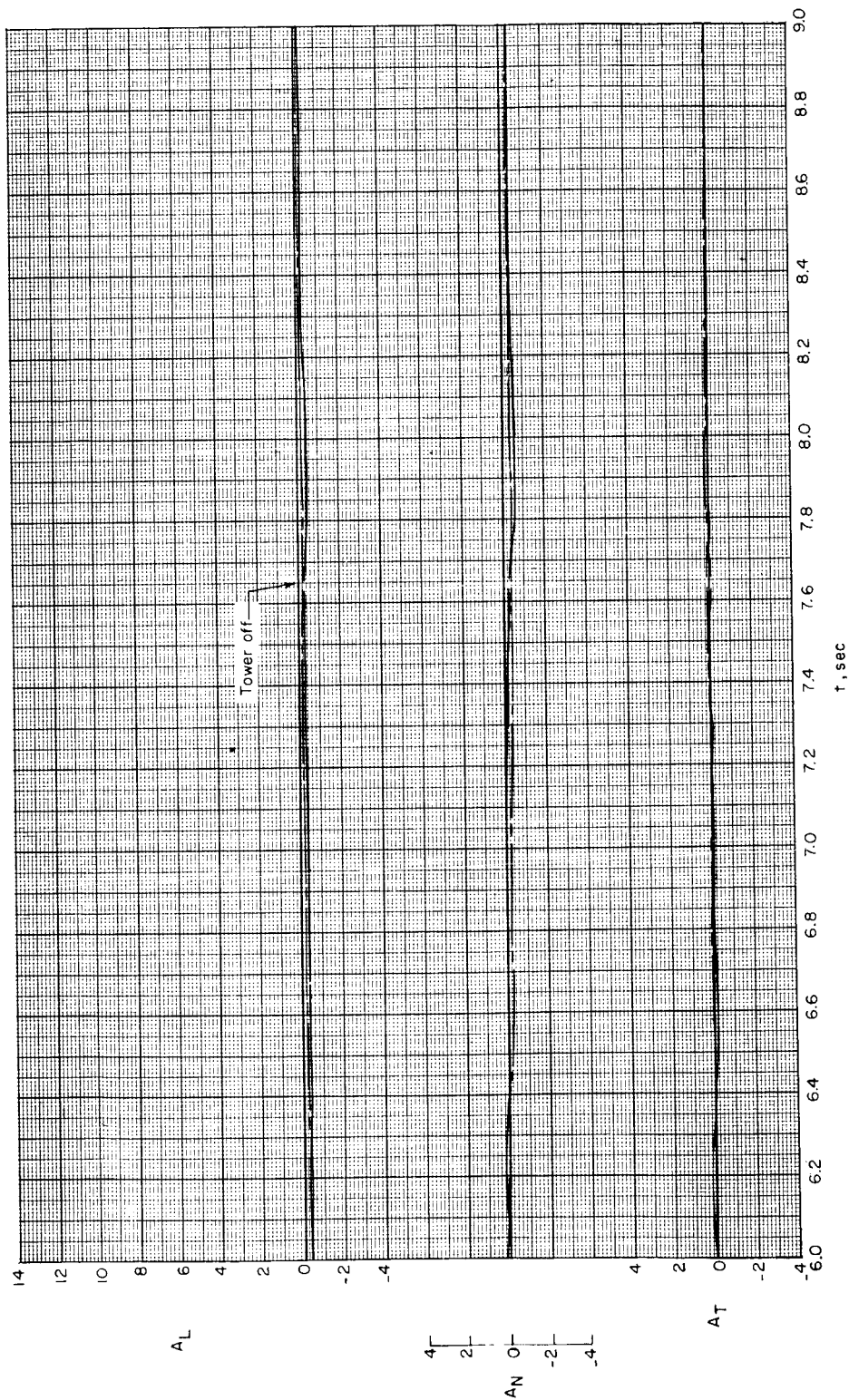


(b) 3.0 to 6.0 seconds.

Figure 12.- Continued.

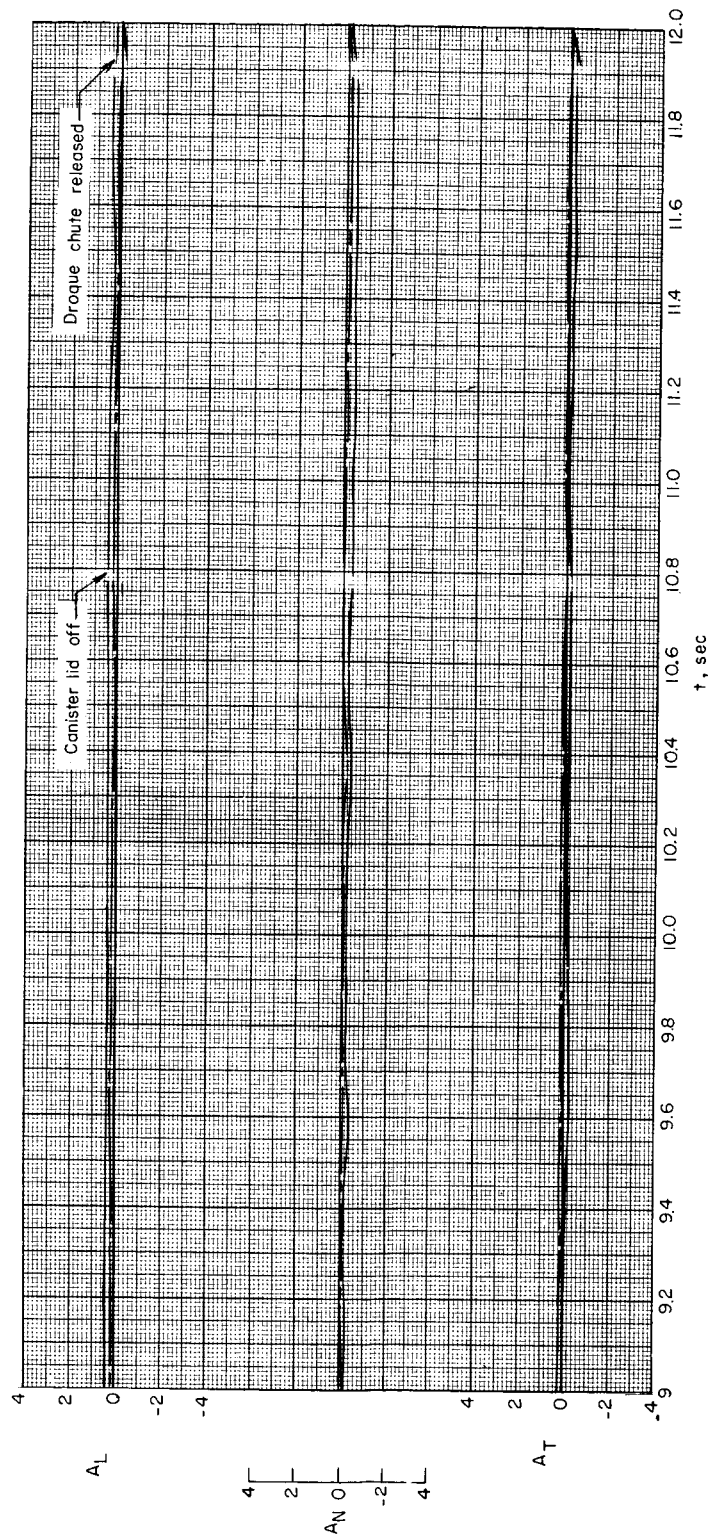
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(c) 6.0 to 9.0 seconds.

Figure 12.- Continued.

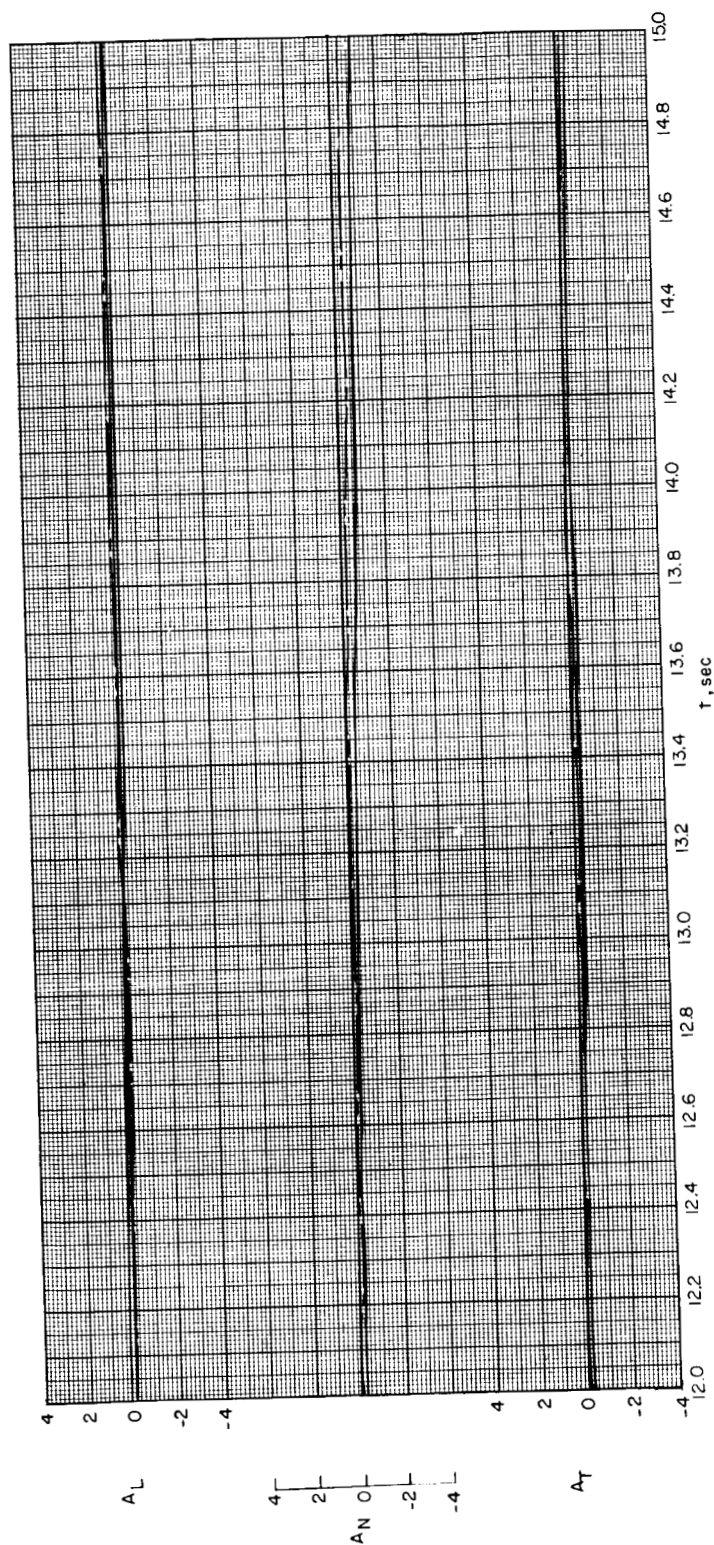


(d) 9.0 to 12.0 seconds.

Figure 12.- Continued.

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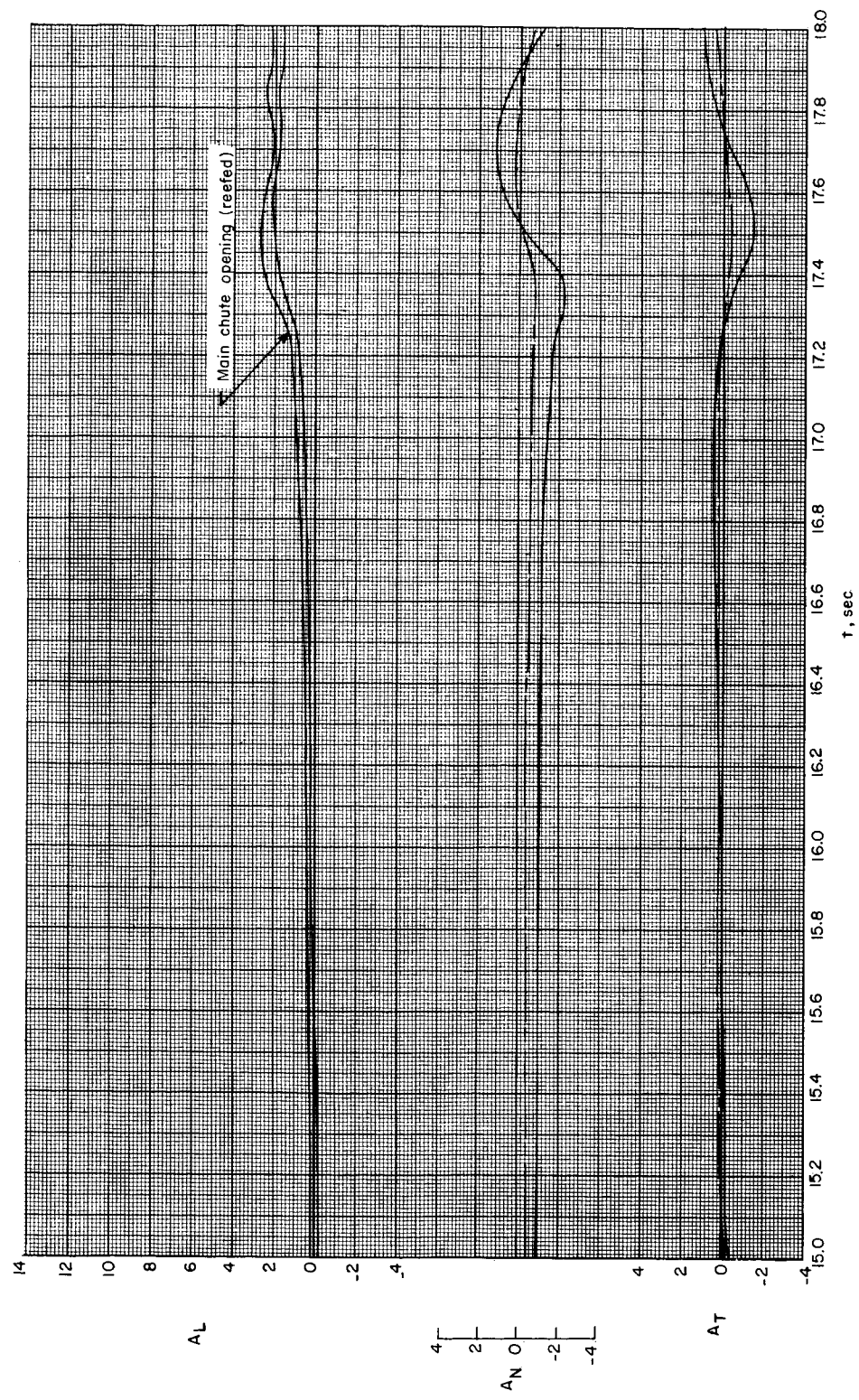
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(e) 12.0 to 15.0 seconds.

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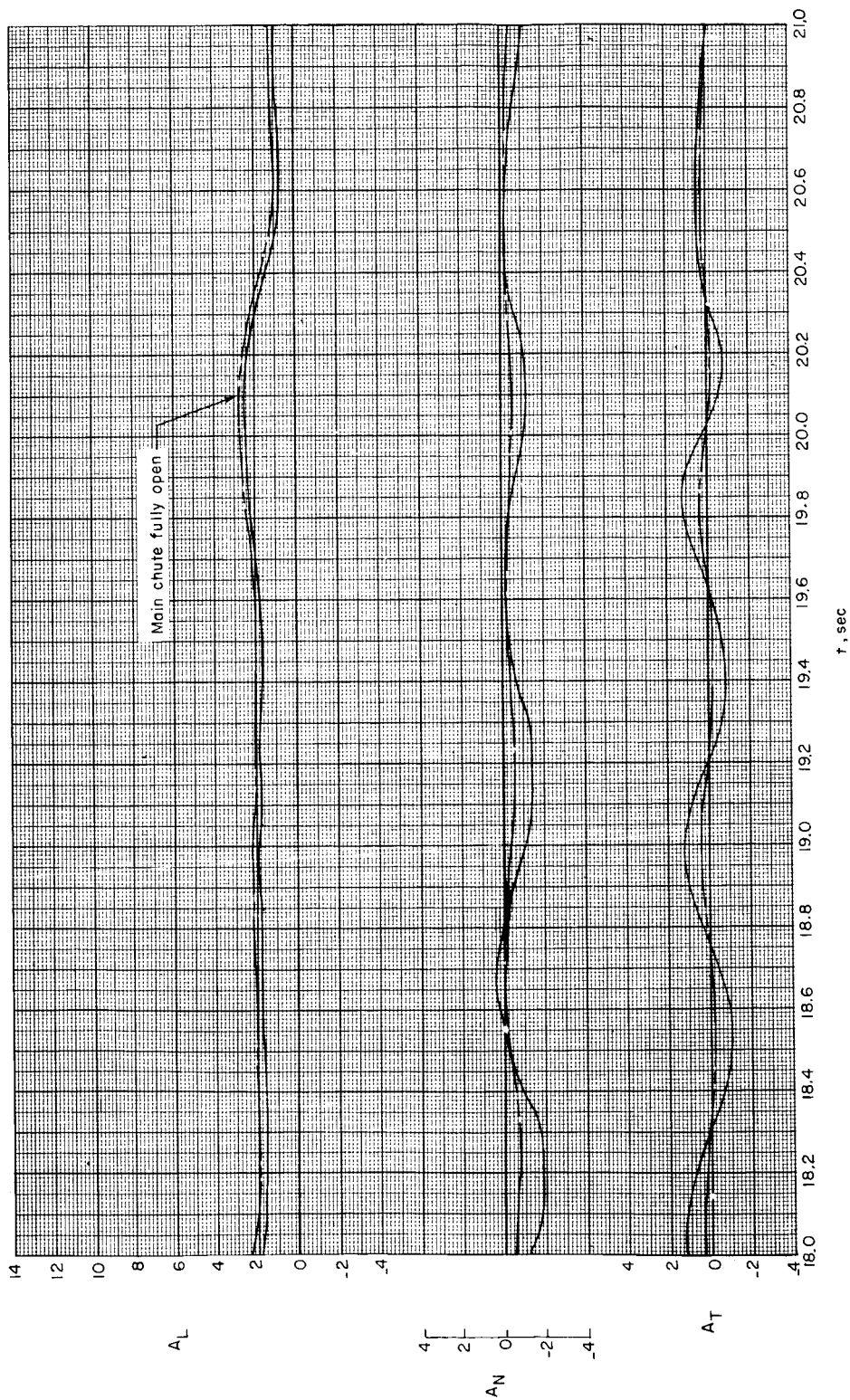
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(f) 15.0 to 18.0 seconds.

Figure 12.- Continued.

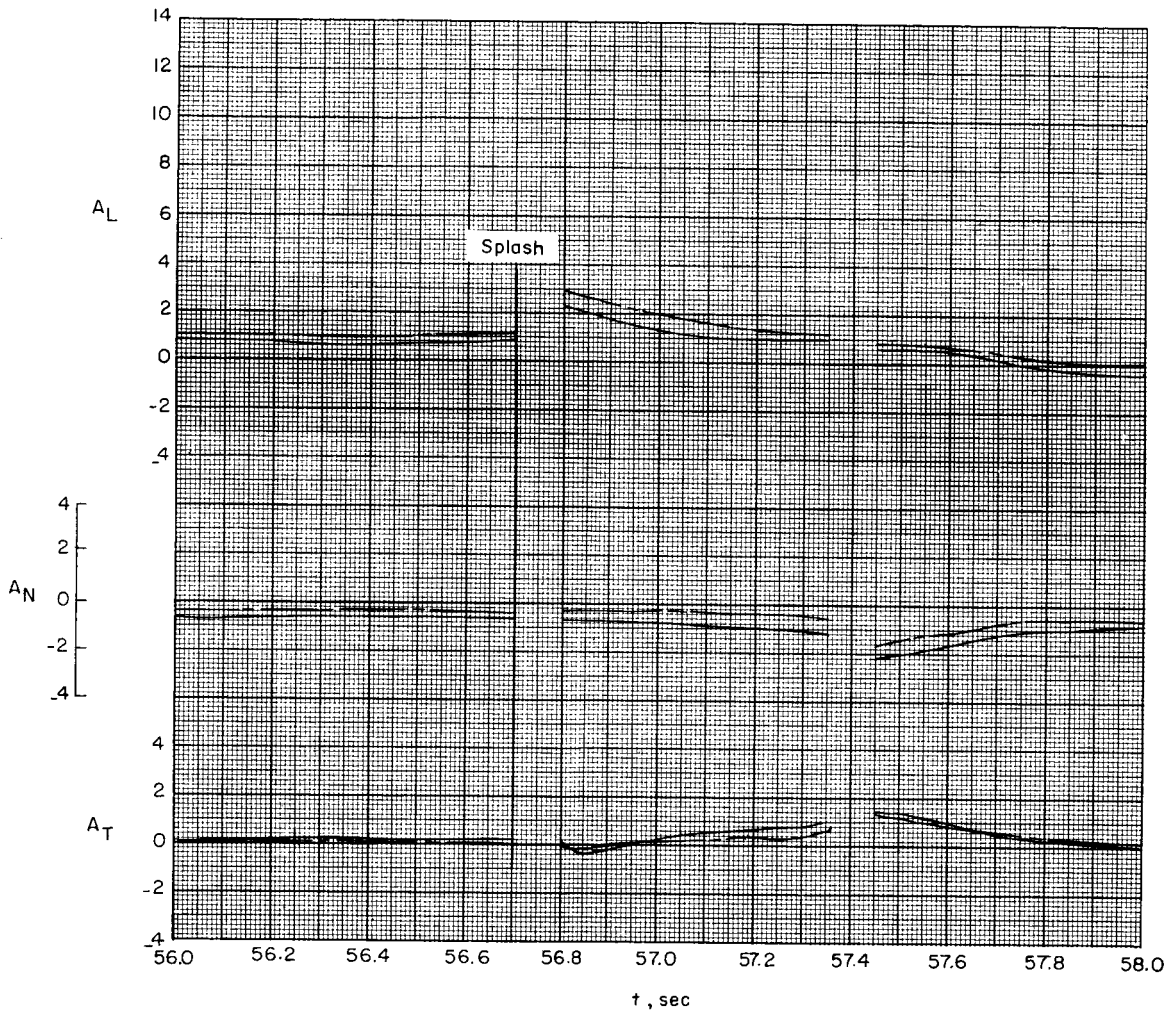
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(g) 18.0 to 21.0 seconds.

Figure 12.- Continued.

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(h) 56.0 to 58.0 seconds.

Figure 12.- Concluded.

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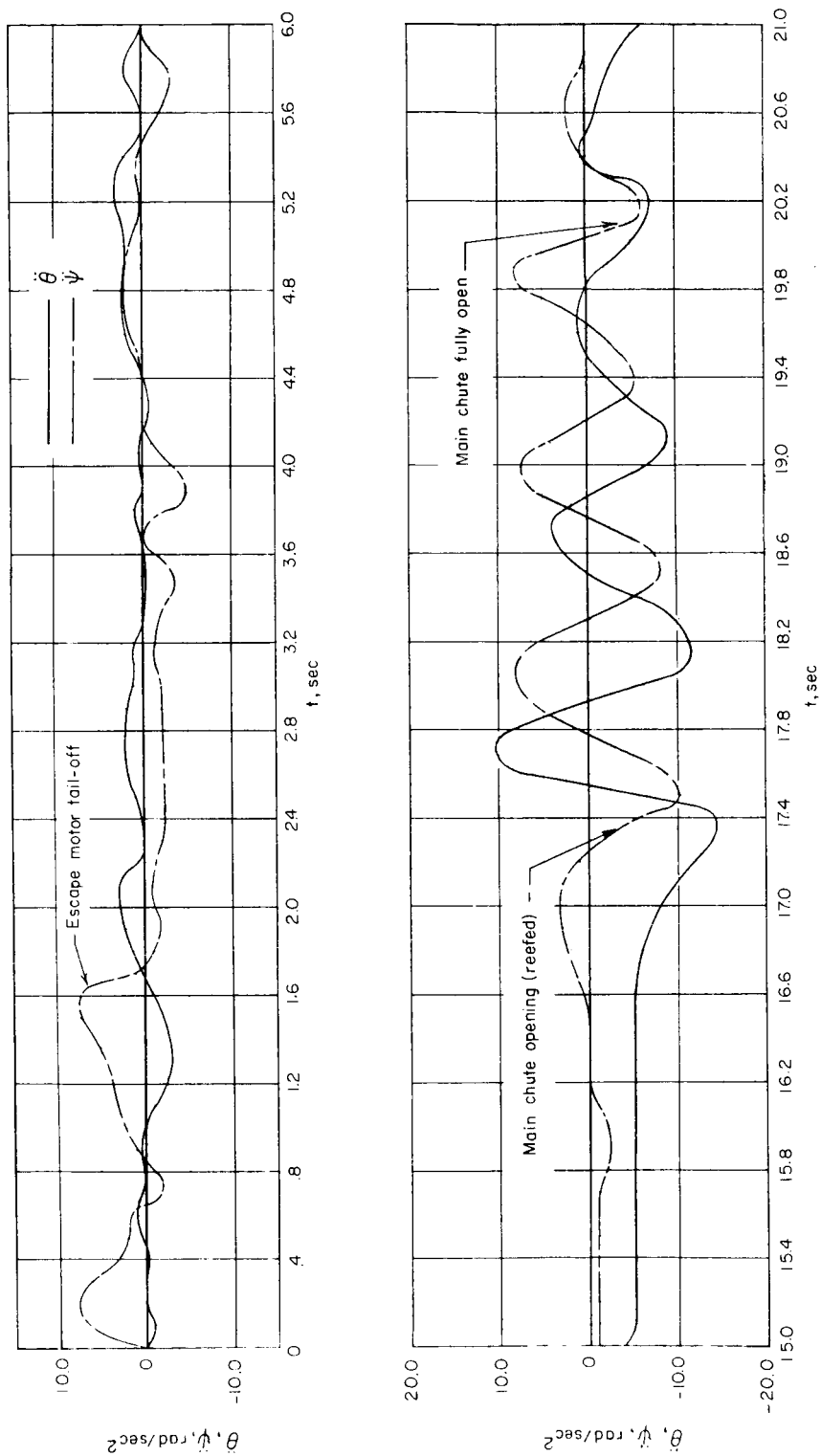


Figure 13.- Variations of angular acceleration in pitch and yaw with time.